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PERUN - THE SYSTEM FOR THE CROP YIELD FORECASTING

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Abstract

PERUN 1.0 is the Windows-based system for probabilistic crop yield forecasting. It is based on crop growth model WOFOST. The weather series is prepared by a stochastic weather generator Met&Roll with parameters that are derived from the observed series. The synthetic weather series coherently extends the available observed series and fit the weather forecast. In the first step, the model yields simulated by WOFOST are validated using observational data for spring barley and winter wheat in Domanínek. Two examples of PERUN 1.0 application are given afterwards. In the first experiment, the crop yield forecast at different days of the year is given for two sample years. In the second experiment, the dependence of the model yields to changes in temperature and precipitation in selected 30-day periods and in the whole year is shown.

1 Introduction: PERUN 1.0

PERUN 1.0 is the computer Windows-based system for probabilistic crop yield forecasting. The system comprises all parts of the process: (i) preparation of input parameters for the crop model simulation, (ii) launching the crop model simulation, (iii) statistical and graphical analysis of the crop model output, (iv) crop yield forecast.

The crop model included in the system is WOFOST version 7.1.1. (Diepen *et al.*, 1989; the software was provided by ALTERRA Wageningen, the Netherlands). Due to the problems with availability and/or reliability of air humidity and wind data, the source code of the crop model was modified (with a permission of the authors of WOFOST) to allow switching between Penman (Penman, 1948) and Makkink (Makkink and van Heemst, 1956) formula for estimating evapotranspiration; Makkink formula does not use wind speed and humidity.

In preparing the input data for WOFOST simulation, the stress is put on the weather data. The weather series is prepared by a stochastic weather generator Met&Roll (Dubrovský, 1996, 1997) with parameters that are derived from the observed series. The synthetic weather series coherently extends the available observed series and fit the weather forecast. Two modifications to the previous version of the generator were made: (1) To use the weather generator with WOFOST model, the wind speed and humidity were added to the standard set of four surface weather characteristics generated by Met&Roll. These two variables are generated separately (after generating the daily series of solar radiation, temperature maximum, temperature minimum, precipitation sum) by nearest neighbours resampling. (2) To prepare weather data for seasonal crop yield forecasting, the weather generator may now generate the synthetic series which coherently follows the observed series at any day of the year.

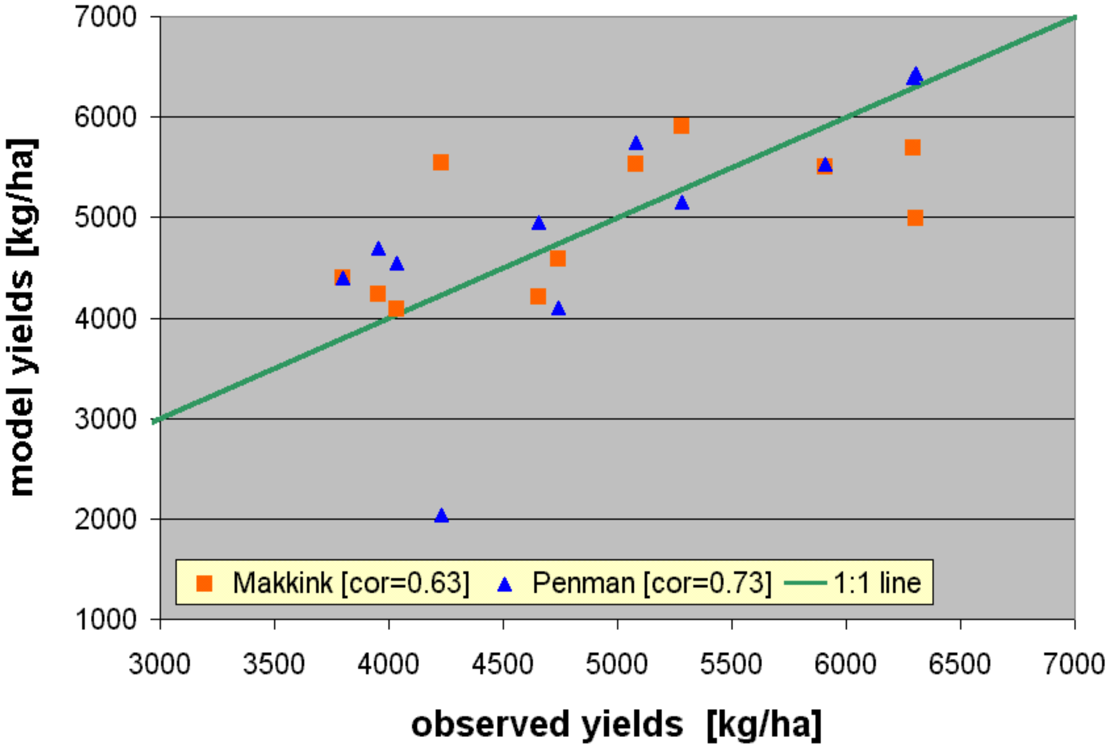

Fig. 1. Validation of the WOFOST crop model. Crop = spring barley (Akcent); site = Domanínek, Czech Republic; data originate from 1990-2000. The evapotranspiration in WOFOST was calculated alternatively by Makkink or Penman formula. The correlation between the observed and model yields is given in the legend box.

Seemingly, the necessary condition for applicability of the system is a successful validation of the crop model and weather generator. Validation of the WOFOST model in terms of the yields of spring barley and winter wheat is shown in Fig. 1 and Fig. 2. However, as the system is still under development and the main purpose of this contribution is to demonstrate applicability of the system, the results of the validation will not be discussed in details here. We only note that a) the winter wheat achieves slightly better fit than the spring barley, (b) the usage of the Penman formula implies slightly better fit than the usage of the Makkink formula. The direct validation (the fit between the statistics derived from the observed and synthetic weather series) of the 4-variate version of the Met&Roll generator was made in Dubrovský (1996, 1997). The fit between the model yields simulated by CERES-Maize crop model with use of the observed and synthetic weather series (indirect validation of Met&Roll) was discussed in Dubrovský *et al.* (2000). The indirect validation of Met&Roll for use with the WOFOST model has not been done by now.

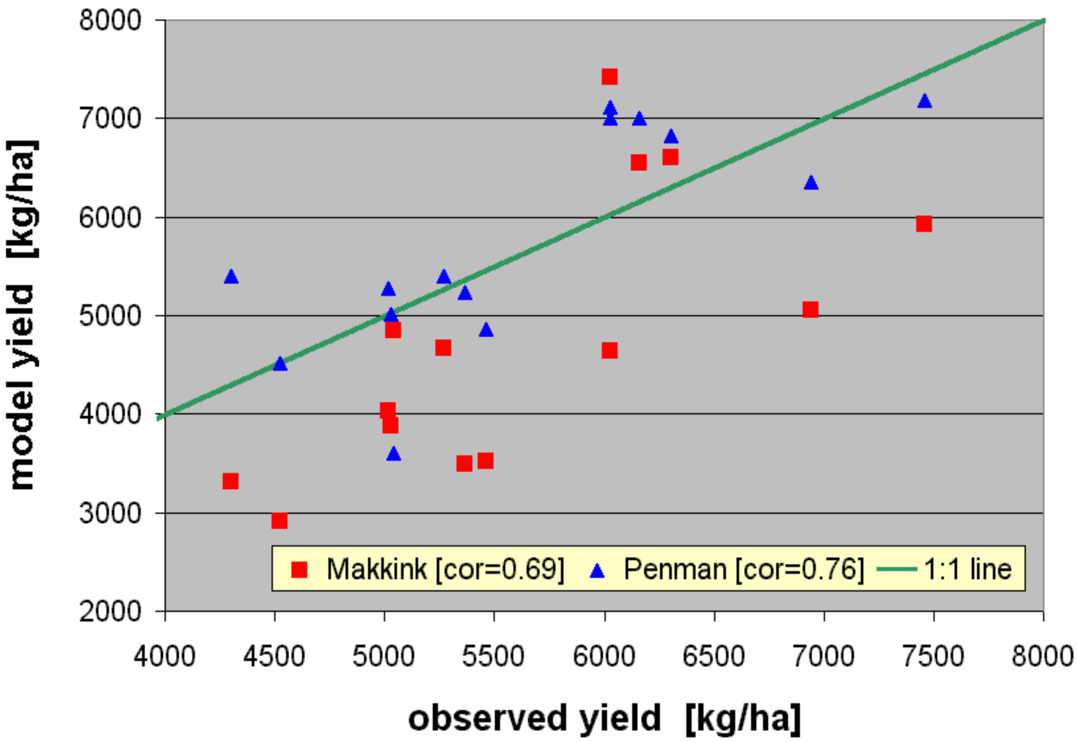

Fig. 2. The same as Fig. 1 but for the winter wheat (Hana), 1985-97.

2 Seasonal crop yield forecasting

2.1 Methodology

Let the crop yield forecast is to be issued on day D and the observed weather series is available till day $D-1$. The crop yield forecast made by PERUN 1.0 is based on crop model simulations run with weather series consisting of observed series till $D-1$ coherently followed up by synthetic weather series since D. The simulation is repeated n times (new synthetic weather series is stochastically generated for each simulation) and the probabilistic forecast is then issued in terms of the average and standard deviation of the model crop yields obtained in the n simulations. The non-weather data (details on the crop, soil and hydrology, water regime; start/end of simulation, nutrients, ...) are the same for all single crop model runs.

The synthetic part of the weather series is prepared by a two-step procedure. In the first step, the daily weather series is generated with parameters of the generator derived from the observed weather series. This assures that the main statistical characteristics of the observed weather series are preserved. In the second step, the synthetic part of the weather series is modified according to the weather forecast. The weather forecast may be given in three formats:

(i) absolute values (e.g., the precipitation sum for the following week will be 50 mm)

(ii) the deviations from the climatology (e.g., the maximum temperature during the following ten days will be 3 degrees above the normal)

(iii) deviations added to the synthetic series (e.g., the values of the temperature in the synthetic series will be increased by 2 degrees within the specified period)

In case of the former two approaches, the weather series is modified so that it exactly fits the weather forecast. To account for the uncertainty, the random component of the forecast weather characteristics may be specified. The weather forecast may be given for a series of arbitrarily long periods. The starting and ending dates of each period and the forecast values of *PREC*, *TMAX* and *TMIN* are defined in a single line for each period. The examples of the former two approaches are given in Table I and Table II.

Table I. Weather forecast given in terms of the absolute values. The forecast is specified for three 10-days periods. JD-from and JD-to are the start and the end (Julian days; format = YYDDD) of the period for which the forecast is valid. The values in the "..std. deviation.." section define the random component.

```
* weather forecast
METHOD  = 1
                ...averages...   ..std. deviation..
@JD-from JD-to  TMAX TMIN PREC   TMAX    TMIN    PREC
99121   99130    17    6  30      2       2       10
99131   99140    14    4  60      3       3       20
99141   99150    21   10  10      4       4       10
@
```

Table II. Weather forecast given in terms of the increments to the long-term averages. See Table I for the legend.

```
* weather forecast
METHOD  = 3
CLIMATE = DOMA.DAY
                ...averages...   ..std. deviation..
@JD-from JD-to  TMAX TMIN PREC   TMAX    TMIN    PREC
99121   99130    -1   -1   1      0       0       0
99131   99140    -1   -1   1      0       0       0
99141   99150    -1   -1   1      0       0       0
@
```

2.2 Experiment I: Crop yield forecasting given at various days of the year

The probabilistic crop yield forecast is based on the multiple crop model simulations. For each simulation, the weather series consists of observed weather series till date $D-1$ and synthetic series thereafter. No weather forecast is assumed in the present experiment, which means that the synthetic series is not modified to fit the weather forecast. The probabilistic forecast is given in terms of <avg±std> interval derived from the set of 30 crop model runs. Seemingly, as the first part (till day $D-1$) of the input weather series is the same for each simulation, the variability of the crop yields derived from the 30 simulations decreases with D increasing.

The crop yield forecast for different days of the year is displayed in Figs. 3-4. In both cases, the site is Domanínek in the Czech Republic and the crop is spring barley. In the first case (Fig. 3; year = 1999), the good fit between the model and observed yields is exhibited (Fig. 3), which is apparent from the fact that the crop yield forecast converges approximately to the observed yield. In this situation, the accuracy of the crop model forecast generally improves with increasing *D*.

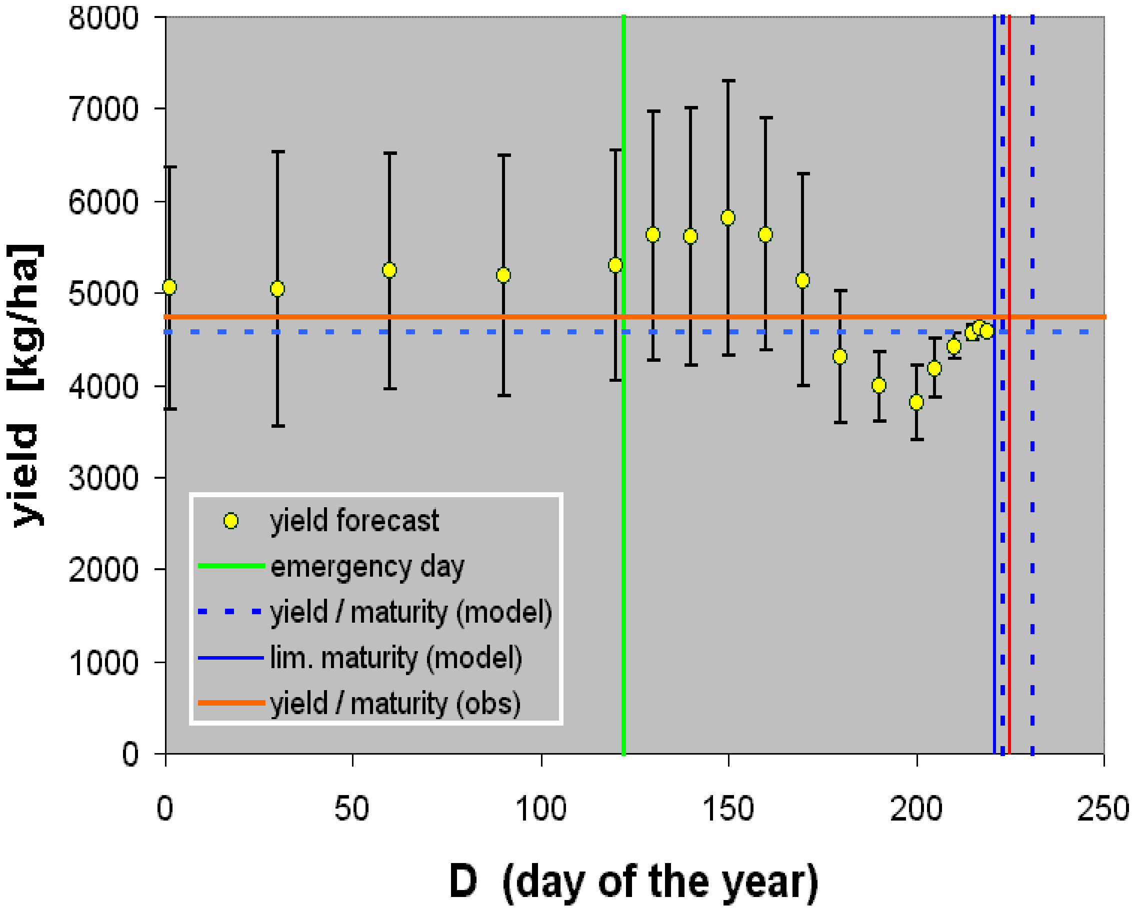

Fig. 3. Forecast of the crop yields with use of the crop model (WOFOST) and the weather generator Met&Roll. Black vertical bars with yellow circles demarcate avg±std derived from 30 simulations with weather series. Site = Domanínek, Czech Republic; crop = spring barley; year = 1999; observed emergency day: vertical green line; observed maturity day: vertical red line; model maturity day (simulated with observed series): vertical blue line; the variability (avg±std) of model maturity day (simulated with synthetic weather series): blue dashed lines; observed yield: horizontal red line; model yield (simulated with observed weather series): blue dashed line.

In the second case (Fig. 4), the crop yield is forecasted for a year (1996), in which the model fails to fit the observed yield. Apparently, the crop yield forecast issued by PERUN 1.0 converges to a wrong value.

The results obtained in the latter case show that the successful utilisation of the system will require future research. Specifically, the task emerges to find indicators of the crop growth/development (indicators should be measurable during the growing period) which could be used to correct the simulated characteristics, thereby allowing more precise crop yield forecast.

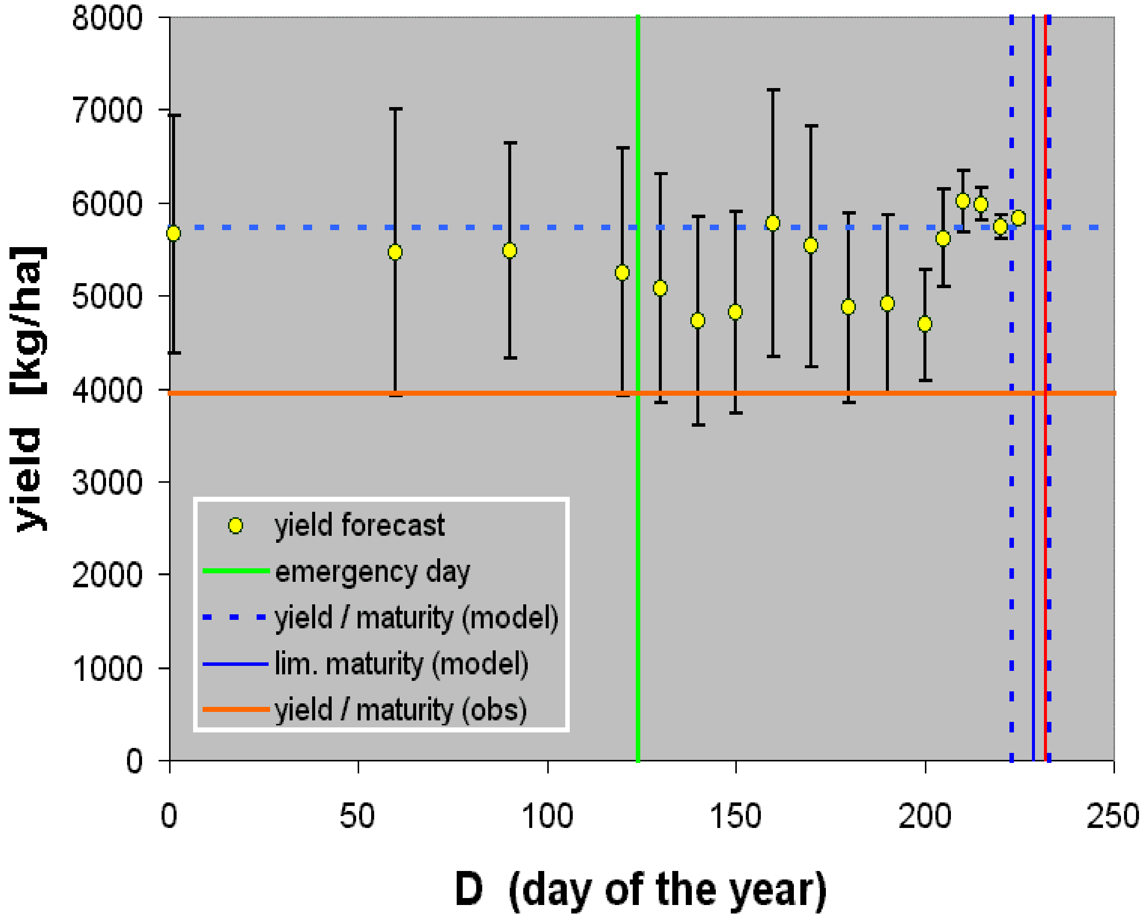

Fig. 4. The same as Fig. 1 but for year = 1996, in which the crop model fails to forecast the yield.

2.3 Experiment II: Sensitivity of prognosed yields to changes in temperature and precipitation

The PERUN 1.0 system may be used to study sensitivity of the crop growth to changes in climatic characteristics in selected periods of the year. For example, one may ask, how the crop yield change if the temperature or precipitation deviates from the mean climatology by a certain increment. Similarly as in the previous experiment, the crop model is now repeatedly run with weather series which consist of observed series till day $D-1$ and synthetic series since day D. However, in contrast with the previous experiment, the 30-day weather forecast is now applied. The forecast defines the changes (with respect to the mean climatology) in temperature or precipitation. In case of the temperature forecast, all daily values in the 30-day period (starting with D) are additively modified so that the mean temperature within the 30-day period equals the climatology increased by ΔT. In case of the precipitation forecast, the values within the 30-day period are multiplicatively modified so that the precipitation sum within the 30-day period equals the climatological mean multiplied by ΔP. The values of ΔT and ΔP are specified by the forecast table. The sensitivity of the forecast yields of barley to changes in temperature and precipitation in three different 30-day periods is displayed in Figs. 5-7. The sensitivity of the yields to changes in temperature and precipitation applied to the whole year is displayed in Fig. 6.

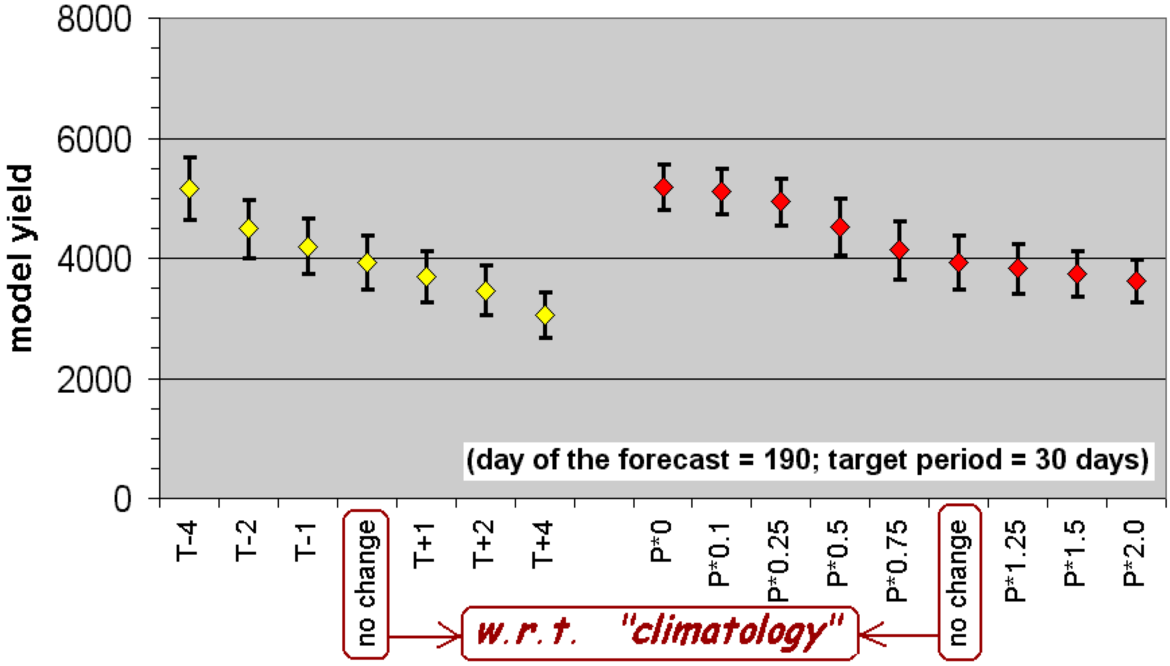

Fig. 5. Sensitivity of the forecast model yields of barley to changes in temperature (T) and precipitation (P). The forecast is given on day D=190 in terms of avg±std (vertical bars) and is based on 30 crop model simulations. The input weather series consist of observed weather series till (D −1)th day of the year and synthetic series since day D. The changes to temperature are additive, the changes to precipitation are multiplicative and the changes to both characteristics are applied to the 30-day period starting on day D. The forecast values are with respect to the mean climatology.

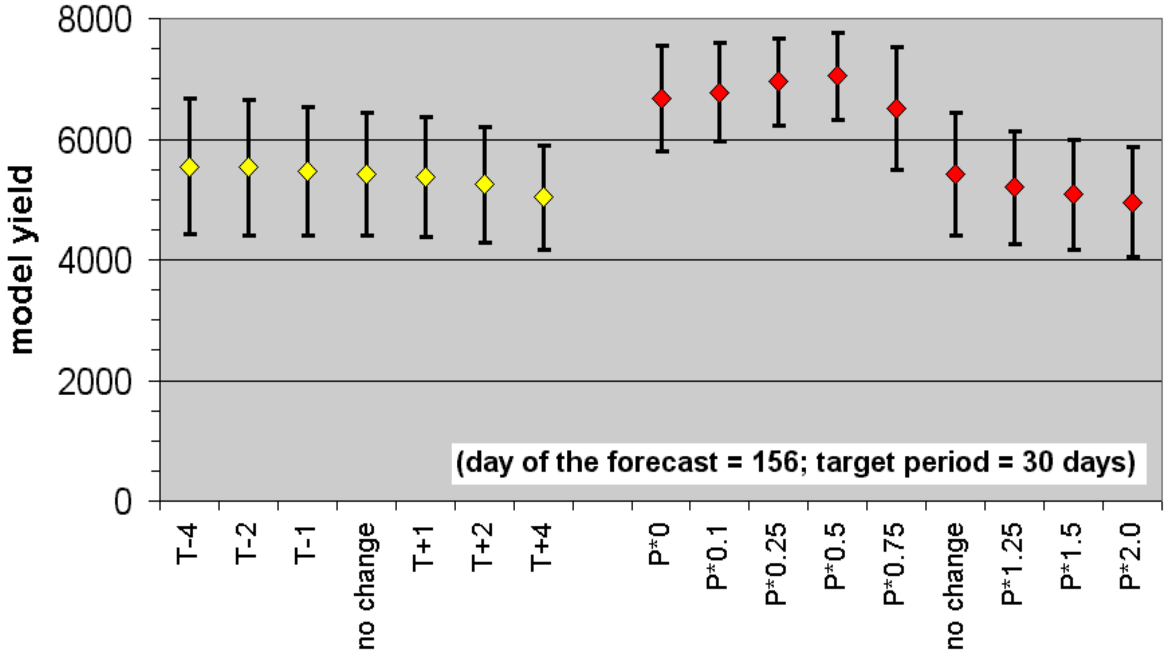

Fig. 6. The same as the previous figure but the forecast is given on day D=156.

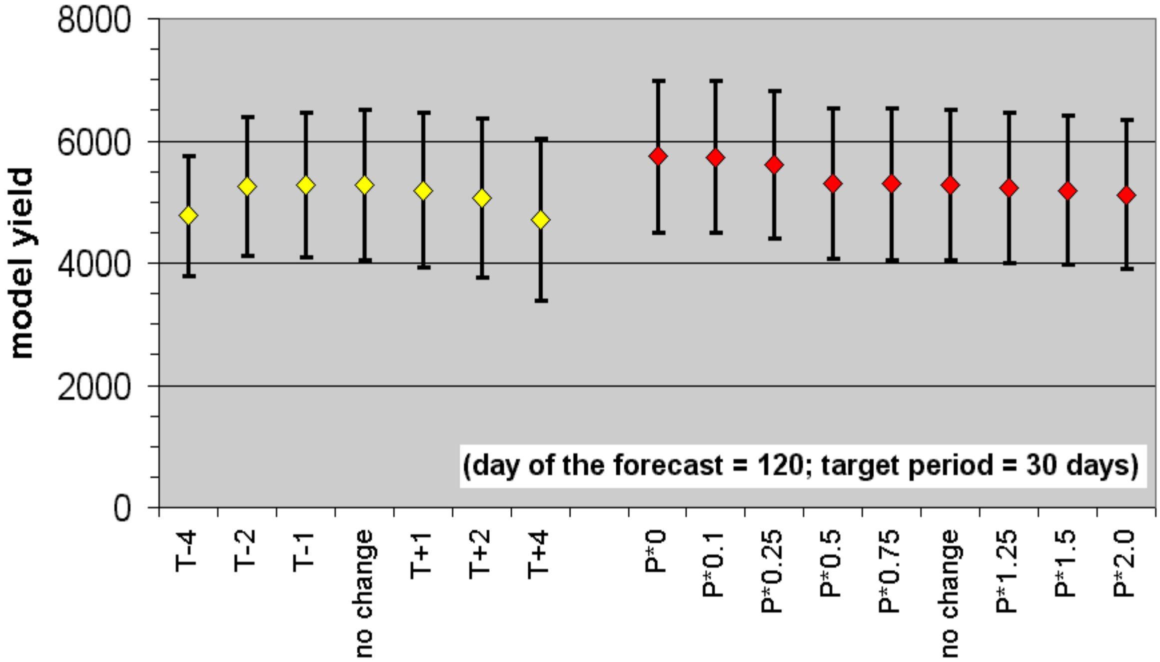

Fig. 7. The same as the previous figure but the forecast is given on day D=120.

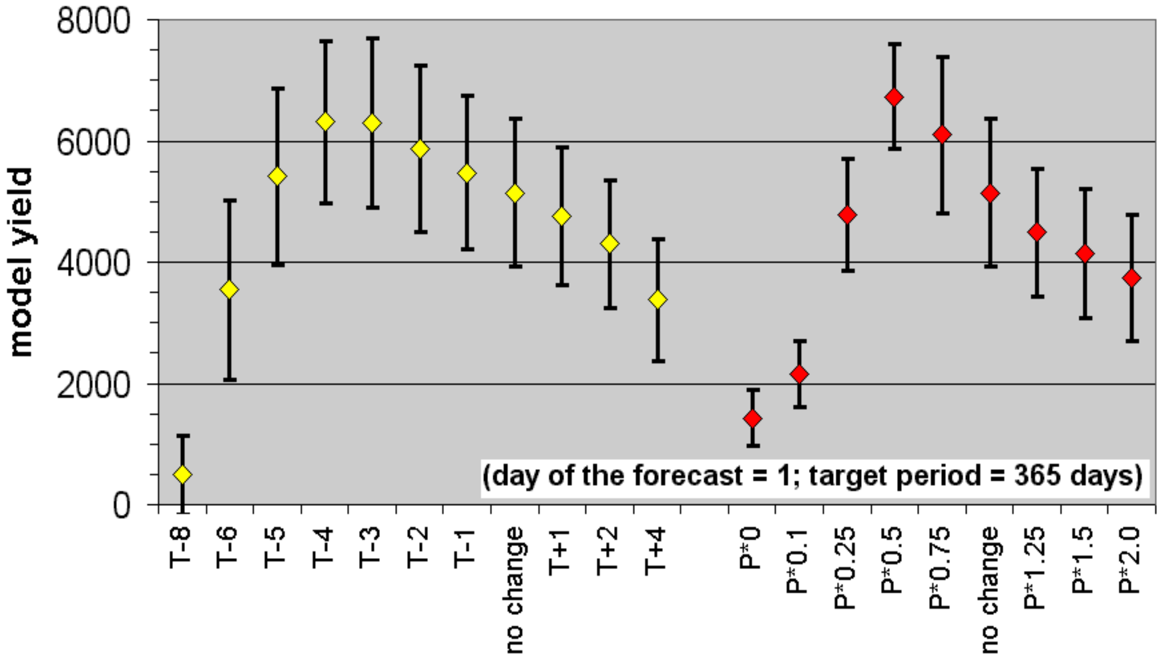

Fig. 8. The same as the previous figure but the synthetic series is generated for the whole year and the changes in temperature and precipitation relate to the whole year, too.

3 Conclusion

The purpose of the contribution was to demonstrate the main functions of the PERUN 1.0 system. Therefore the results (e.g. the effect of the changes in temperature and precipitation on the crop yields) obtained in the experiments were not discussed.

As for the usage of the system for crop yield forecasting, it may be noted here that the successful utilisation of the system will require future research. Specifically, the task emerges to find indicators of the crop growth and development (indicators should be measurable during the growing period) which could be used to correct the simulated characteristics, thereby allowing more precise crop yield forecast.

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PERUN - systém pro prognózu výnosů obilnin

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souhrn: Předpovědní systém PERUN 1.0 je určen k simulaci růstu a především prognóze výnosu pšenice ozimé a ječmene jarního jako dvou principiálních obilnin v ČR za rozličných meteorologických podmínek. Jeho jádro tvoří růstový model WOFOST v. 7.1.1. spolu se stochastistickým generátorem Met&Roll. Jde o aplikaci, která v postupných krocích umožňuje vytvořit databázi vstupních dat, spuštění simulací a konečné statistické a grafické zpracování výsledků – včetně vydání pravděpodobnostní prognózy výnosu. Model WOFOST byl modifikován tak, aby v závislosti na dostupnosti a kvalitě vstupních meteorologických dat umožnil zvolit jednu ze dvou metod výpočtu evapotranspirace (Makkink, Penman). Prvním předpokladem použitelnosti systému PERUN 1.0 je jeho validace pomocí několikaleté řady experimentálních dat. Dosavadní výsledky validací provedených na lokalitě Domanínek ukazují nejvyšší míru spolehlivosti modelu při předpovědi výnosů ozimé pšenice a výpočtu evapotranspirace dle Penmana (r = 0,76). Samotná prognóza výnosu je založna na simulaci růstovým modelem s použitím denních meteorologických charakteristik, jejichž řada se skládá ze dvou částí (ostatní data jsou identická pro celou sezónu): (i) pozorové hodnoty až do dne předcházejícího dnu vytváření předpovědi (D-1), (ii) ode dne D jsou použity hodnoty vygenerované stochastickým generátorem a modifikované na základě dlouhodobé předpovědi. Pravděpodobnostní předpověď výnosu vychází ze statistického zpracování vícenásobně opakované simulace, přičemž pro každou jednotlivou simulaci je druhá (syntetická) část vstupní meteorologické řady vygenerována znovu. Meteorologickou přepověď je možné zadat v různých formátech. Součástí článku jsou výsledky prognóz výnosu na lokalitě Domanínek v letech 1996 a 1999 spolu s analýzou citlivosti výnosu ke změnám hodnot teplot a srážek během vegetace. Dosavadní výsledky dokazují nezbytnost provést detailní validaci systému PERUN 1.0 na větším počtu lokalit a zároveň hledat specifické indikátory růstu a vývoje daných plodin. Tyto indikátory by měly být snadno měřitelné během vegetace a jejich účelem je zpřesnění vydávaných předpovědí.